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The Effect of Gas Supersaturated Water on Juvenile Chinook *(Oncorhynchus tshawytscha)* Held in Cages in the Nechako River, British Columbia

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November 1988

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1671

Fisheries and Oceans Pêches et Océans

Canada

89-04427/

Canadian Technical Report of Fisheries and Aquatic Sciences

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THE EFFECT OF GAS SUPERSATURATED WATER ON JUVENILE CHINOOK (*Oncorhynchus tshawytscha*) HELD IN CAGES IN THE NECHAKO RIVER, BRITISH COLUMBIA

by

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Cat. No. Fs 97-6/1671E ISSN 0706-6457

Correct citation for this publication:

Rowland, D. E. and J. O. T. Jensen. 1988. The effect of gas supersaturated water on juvenile chinook (Oncorhynchus tshawytscha) held in cages in the Nechako River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1671: 57 p.

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ABSTRACT

Rowland, D. E. and J. O. T. Jensen. 1988. The effect of gas supersaturated water on juvenile chinook (Oncorhynchus tshawytscha) held in cages in the Nechako River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1671: 57 p.

The Nechako River, a major tributary of the Fraser River in British Columbia, supports a large salmonid population. Elevated levels of total gas pressure (TGP) have been documented in the water below Cheslatta Falls, which is a barrier to upstream migration on the Nechako mainstem. In July and August 1985 and 1986, in situ studies using juvenile chinook (Oncorhynchus tshawytscha), rainbow trout (Salmo gairdneri) and mountain whitefish (Prosopium williamsoni) were conducted to determine if the excess TGP was causing gas bubble trauma (GBT). Gas bubble trauma is a non-pathogenic response of aquatic organisms to gas supersaturation. This report discusses these studies, emphasizing the 1986 results.

In 1986 fish were held at two sites on the river, one near the base of Cheslatta Falls and a second 30 km downstream. There were three treatments at each site; fish held at the surface, at 1 m depth and volitionally, where they were free to move in the upper 1 m of the water column. One fish at the Cheslatta Falls site showed definitive symptoms of GBT after 15 days of exposure. Measurements of TGP ranged from 107.2 to 115.0%, averaging 111.0%. The mortality rate at this site indicated a strong trend associated with gas supersaturation; at 11 to 13 days of exposure, the cumulative mortality rates in the surface and volitional cages were approximately twice that of fish held at depth, where water pressure compensates for excess TGP. However, this trend did not continue as mortality occurred in all treatments. Factors unique to field studies of GBT (versus laboratory or hatchery study) are also discussed.

RÉSUMÉ

Rowland, D. E. and J. O. T. Jensen. 1988. The effect of gas supersaturated water on juvenile chinook (Oncorhynchus tshawytscha) held in cages in the Nechako River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1671: 57 p.

Une population nombreuse de salmonidés fréquente la rivière Nechako, un tributaire important du fleuve Fraser en Colombie-Britannique. On a déjà observé des niveaux élevés de pression gazeuse totale dans les eaux en aval des chutes Cheslatta, qui constituent une barrière pour les saumons qui veulent remonter le cours principal de la rivière Nechako. Au mois de juillet et au mois d'août 1985 et 1986, nous avons fait des études sur le terrain avec des saumons quinnats juvéniles (Oncorhynchus tshawytscha), des truites arc-en-ciel (Salmo gairdneri) et des ménominis de montagnes (Prosopium williamsoni) pour savoir si cette pression gazeuse totale élevée pouvait causer un traumatisme gazeux. Le traumatisme gazeux est une réaction non pathogène des organismes aquatiques à une sursaturation de l'eau en gaz. Ce rapport présente ces études en mettant l'accent sur les résultats de l'année 1986.

En 1986, nous avions deux sites expérimentaux sur la rivière, un près de la base des chutes Cheslatta et l'autre à 30 km en aval. Nous avons pratiqué trois traitements à chacun de ces sites: le premier traitement consistait à maintenir les poissons en surface, le deuxième consistait à les maintenir à une profondeur d'un mètre tandis que dans le troisième traitement, les poissons pouvaient nager librement dans le premier mètre de la colonne d'eau. Au site situé près de la base des chutes, un poisson a montré des symptômes irrémédiables du traumatisme gazeux 15 jours après le début du traitement. La pression totale variait entre 107,2 et 115,0 % et sa moyenne était de 111,0 %. À ce site, le taux de motralité était fortement relié à la sursaturation en gaz: après 11 à 13 jours de traitement, les taux cumulatifs de mortalité dans les cages de surface et dans celles qui couvraient le premier mètre de la colonne d'eau étaient approximativement deux fois plus élevés que celui des poissons maintenus à 1 mètre de profondeur où la pression de l'eau contrebalance la pression excessive des gaz. Cependant, les effects de la sursaturation en gaz sur le taux de mortalité n'ont pas maintenu la même tendance car il y a eu mortalité dans tous les traitements. Les caractéristiques particulières des études sur le terrain portant sur le traumatisme gazeux (par rapport aux études en laboratoire ou réalisées dans des aleviniers) sont aussi examinées.

INTRODUCTION

Chinook salmon, sockeye salmon (O. nerka), rainbow trout (Salmo gairdneri), and other fish species utilize the Nechako River, a large northern tributary of the Fraser River, British Columbia.

In December 1950, the Province of British Columbia issued a water licence to the Aluminum Company of Canada (Alcan) to develop storage capacity in the Nechako River watershed upstream of Cheslatta River and in the Nanika River watershed upstream of Glacier Creek. Development of the Nechako system, labelled Kemano I, involved construction of the 91.5 m (300 ft) rock filled Kenney Dam at Grand Canyon on the upper Nechako River. There is no discharge of water at the dam and the old riverbed carries only seepage between the dam and Cheslatta Falls. At the western end of the reservoir a 17 km (10 mi) diversion tunnel supplies water to hydro-electric generating facilities on the Kemano River, about 16 km (10 mi) upstream from Gardner Canal on the British Columbia coast (Fig. 1). Release of surface water from the 907 sq km (350 sq mi) Nechako Reservoir behind the dam occurs at Skins Lake spillway, flows through a chain of lakes and plunges over Cheslatta Falls, entering the Nechako riverbed at Cheslatta Flats.

A wide range of studies have been undertaken by government agencies and Alcan to determine the impacts of existing and further proposed developments on fish. One area of study has involved assessing the origin and impact of elevated levels of dissolved atmospheric gases in the Nechako River. During some periods of the year, Nechako River water contains substantially more dissolved atmospheric gas than would water at equilibrium with the atmosphere. This supersaturation occurs primarily as a result of air entrainment at Cheslatta Falls. Aquatic organisms in such an environment can develop gas bubbles or emboli in their organs, tissues and vascular systems. In fish, the problem is commonly termed "gas bubble disease" or more appropriately "gas bubble trauma" as the cause is physical rather than pathogenic. Symptoms of GBT vary according to the level of supersaturation, duration of exposure and species and age (life cycle stage) of fish. Salmonids are among the least tolerant fish species. Acute and chronic toxicity result in net reduced yield (Weitkamp and Katz 1980).

Prior to 1985, measured and modelled dissolved total gas pressure (TGP) values suggested that Nechako River supersaturation levels were sufficient to cause chronic or acute toxicity (Alderdice and Jensen 1985). Therefore in situ GBT studies were conducted on the Nechako River in the summers of 1985 and 1986. The object of these field studies was to determine the biological effects of supersaturated Nechako River water on fish. Chinook, rainbow trout and mountain whitefish fry were used in the preliminary 1985 studies which were accompanied by TGP studies.

The key results of the 1985 studies were first, the appearance of external symptoms of GBT in one fish and second, a high incidence of haemorrhaging in the fins and eyes of fish, which can be symptomatic of GBT. In retrospect, the 1985 study periods were too short (12 days of exposure or

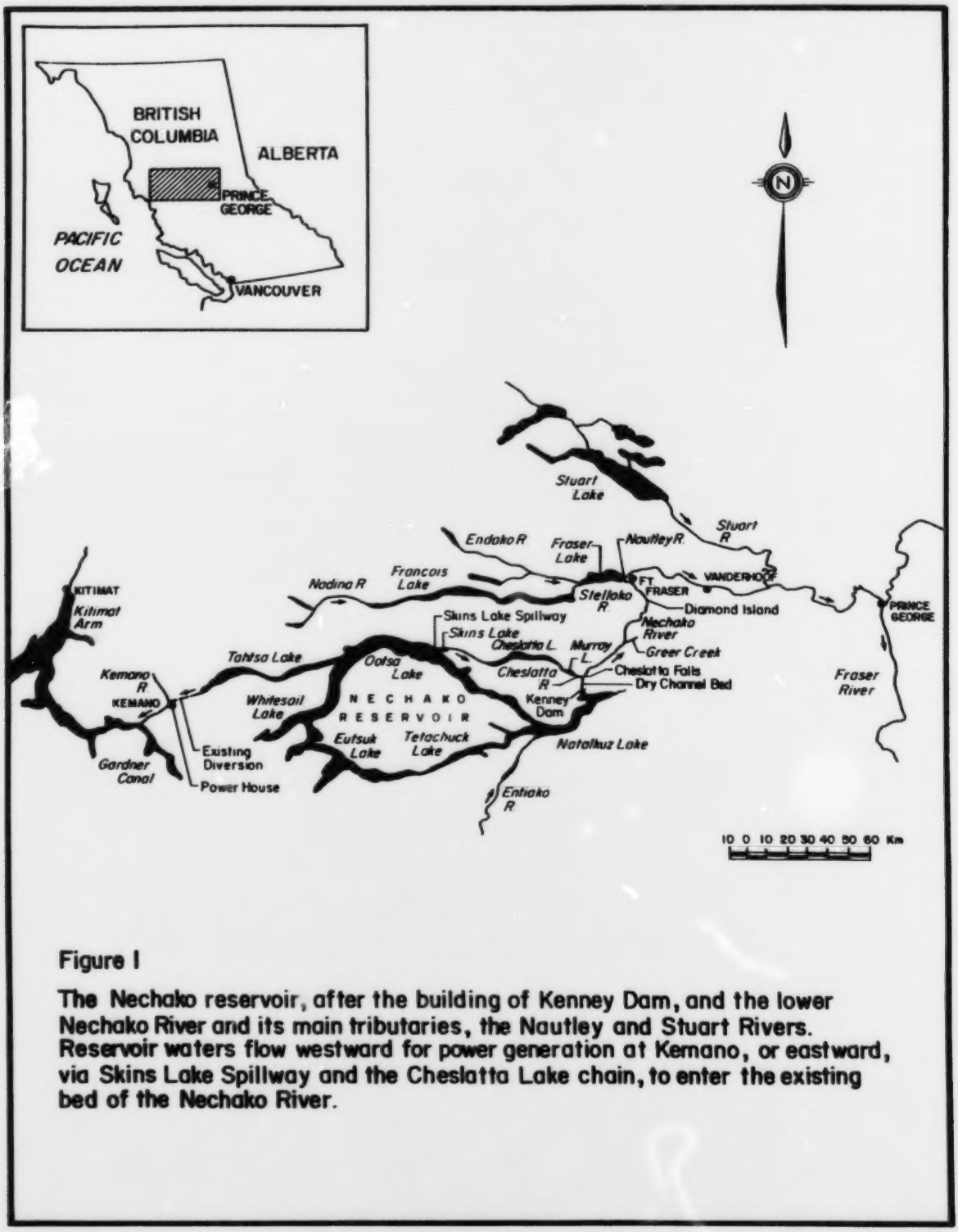

Figure I

The Nechako reservoir, after the building of Kenney Dam, and the lower Nechako River and its main tributaries, the Nautley and Stuart Rivers. Reservoir waters flow westward for power generation at Kemano, or eastward, via Skins Lake Spillway and the Cheslatta Lake chain, to enter the existing bed of the Nechako River.

less) and the TGP levels too low (107.6 to 112.6%) for significant mortality or extensive external symptoms of GBT to appear. The experimental design was dependent on stable flows and the tests were concluded after 9 to 12 days when flows changed. Further modelling work by Jensen et al. (1986) suggested that at least 20 to 30 days exposure would be required for GBT symptoms to appear at those TGP levels.

The main objective of the 1986 field study was to expose resident (Nechako River) juvenile chinook to typical TGP levels that occur during periods of high discharges in summer. In addition, continuous monitoring of TGP was conducted near the base of Cheslatta Falls. This paper presents the study results.

METHODS AND MATERIALS

In 1986, fish were held in the Nechako River in cylindrical cages supported in a floating holding pen framework (Fig. 2). Cages were held at surface and 1 m (3.2 ft) depth regardless of stage. The fish in cages at 1 m depth functioned as control fish. They were exposed to the same water quality as surface fish with the exception that they were hydrostatically compensated and experienced TGP levels 10% less than fish at surface. `Volitional' cages, which allowed fish to move freely in the upper metre of the water column, were also installed. Two holding pen sites were chosen, one located 0.5 km (0.3 mi) downstream of Cheslatta Falls, with a second site 30 km (19 mi) downstream of the falls adjacent to Frank Schumans' property (Fig. 3).

The period of study extended from July 18 to August 16, 1986. Discharge as measured at Water Survey of Canada (WSC) Station 08JA017, Nechako River below Cheslatta Falls, ranged from 150 CMS (5300 cfs) to 278 CMS (9800 cfs).

The holding pens were constructed of 2 x 4 and 2 x 6 stock with plywood gusset reinforced corners. The sections were bolted together and vinyl garden fencing 1.21 m (4 ft) wide was stapled to the bow and side panels. Plywood enclosed 2.44 m x 0.30 m x 0.30 m (8 ft x 1 ft x 1 ft) styrofoam floats were attached to vertical rails on the sides of the pen. Nine vertical dowels, used to support the cages (described below) within the pen, were supported using horizontal cross members attached to the bottom of the pen and the top of the float rails.

The cages, rented from Coastline Environmental Services Ltd., were constructed of 6.35 mm (0.25 in) opening vexar (plastic) mesh formed into a cylinder 30 cm (12 in) in diameter and 75 cm (30 in) in length providing a cage volume of approximately 53 l (14 gal) (Fig. 4). Access was through a zippered opening running the length of the cage. An aluminum framework supported the mesh cylinder.

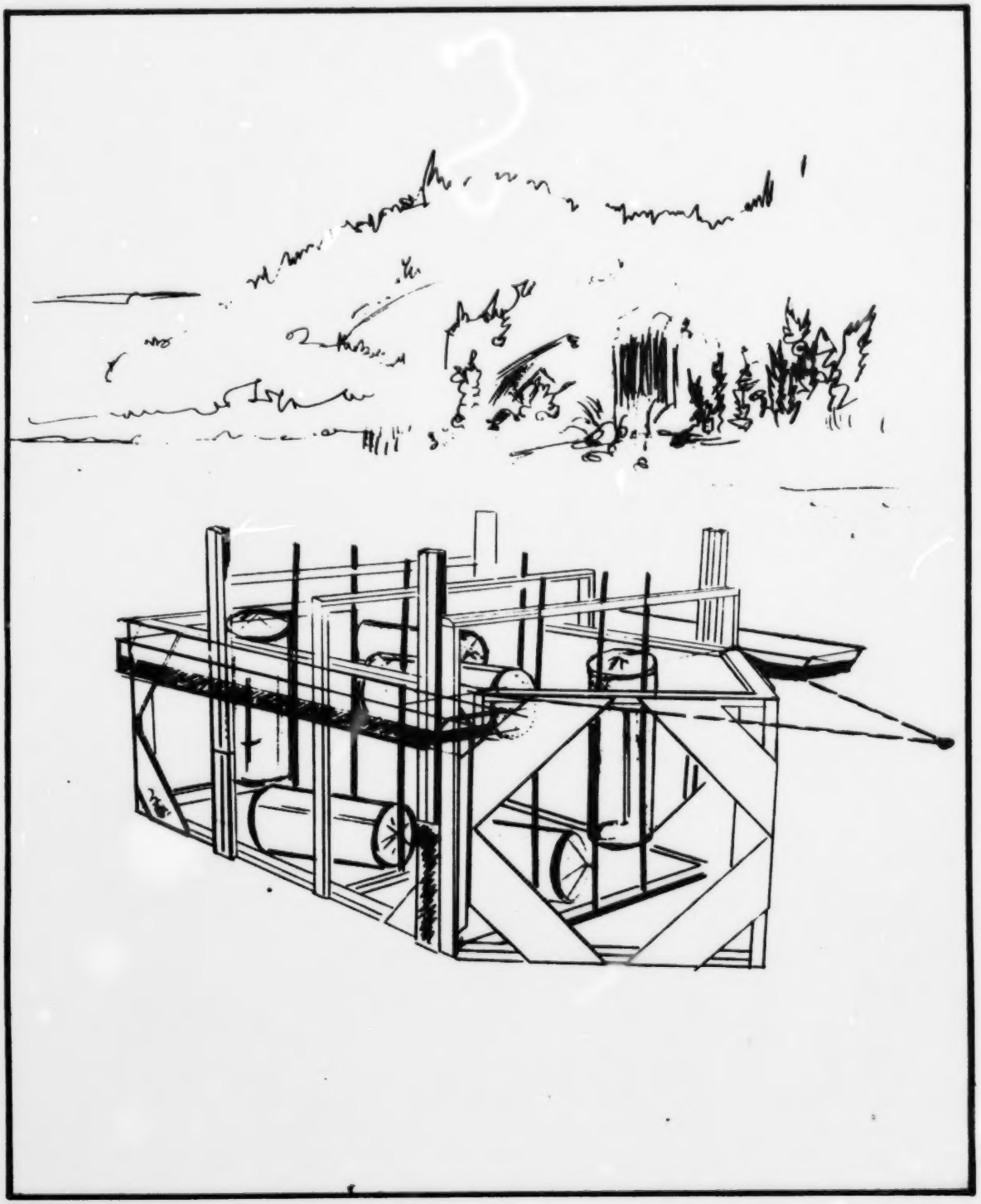

Figure 2 **Artist's Rendering of Holding Pen and Cages at Cheslatta Falls Site**

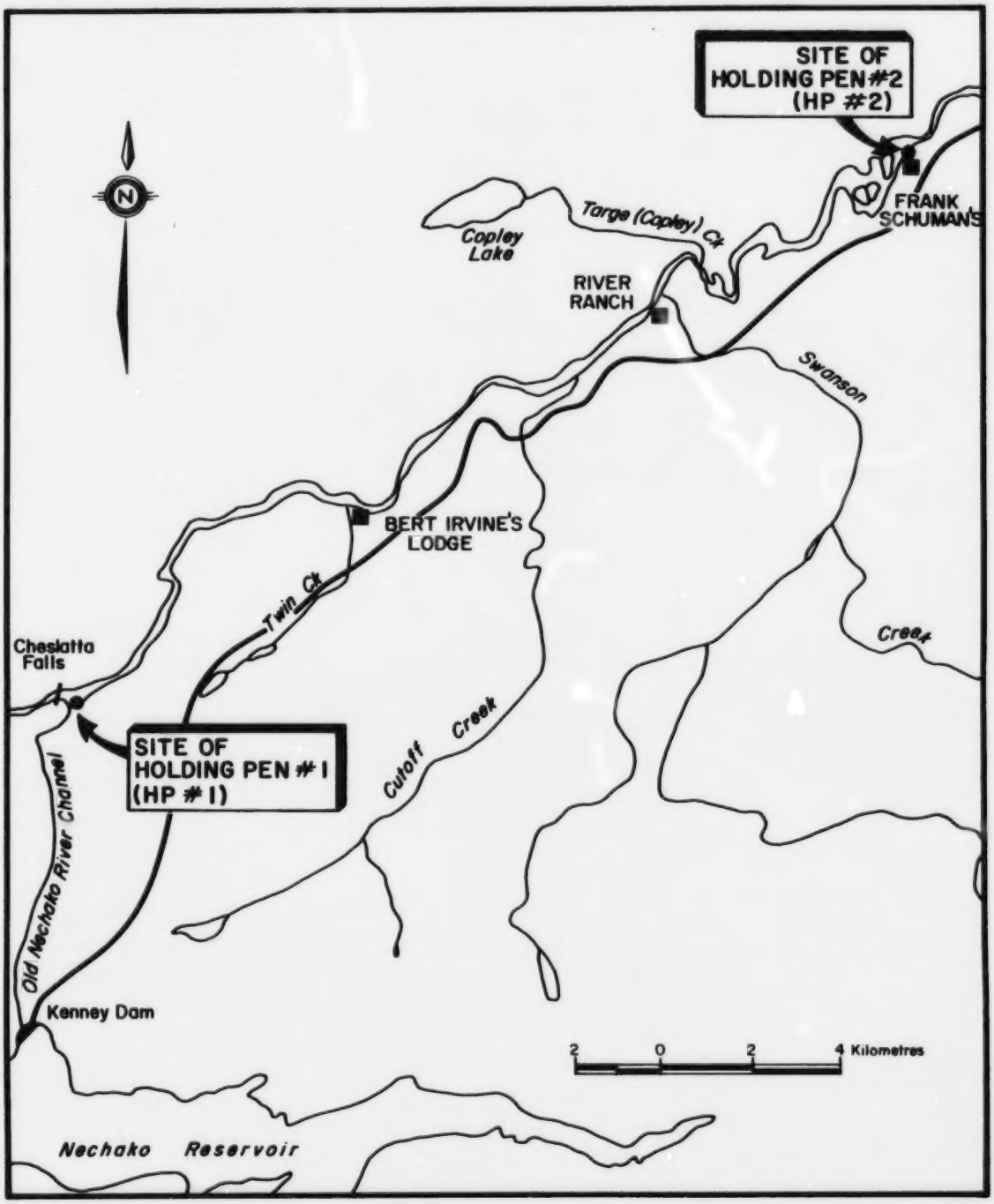

Figure 3 1986 Nechako River Gas Bubble Trauma Study Area Showing Test Sites HP#1 and HP#2

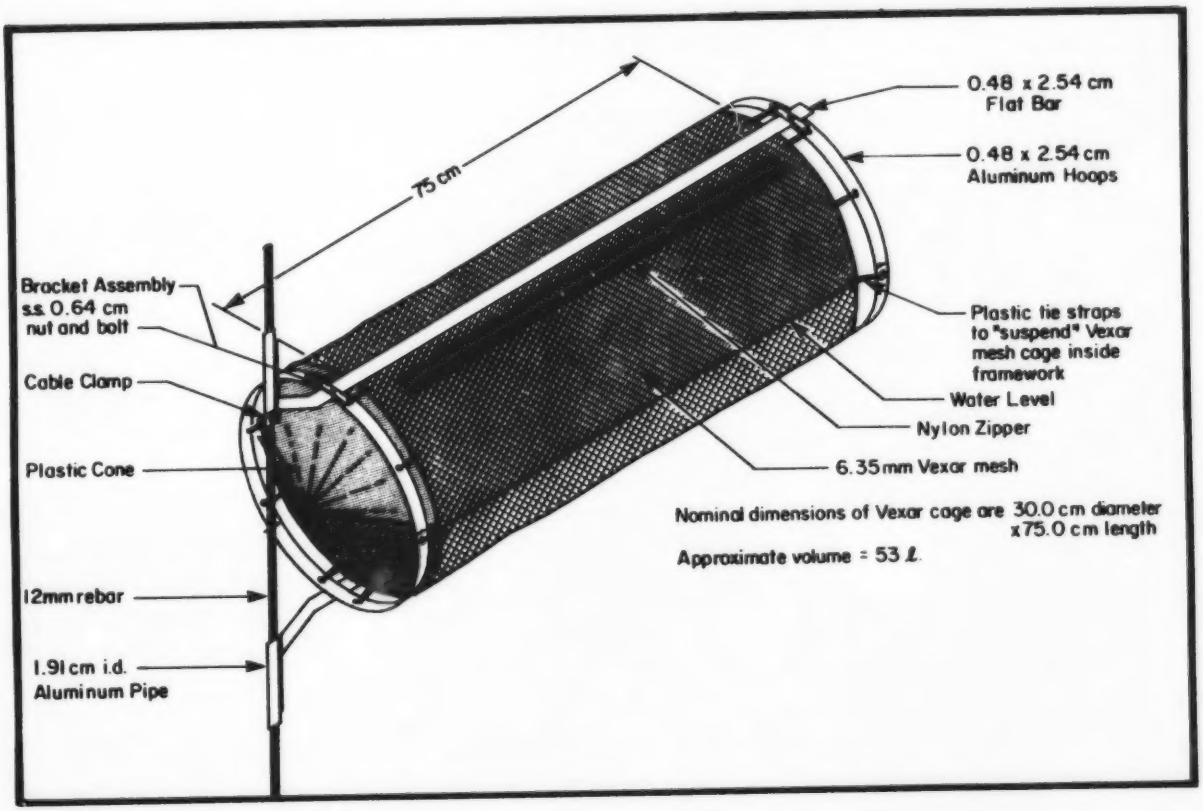

Figure 4 **Cages for Gas Bubble Trauma Studies**

Six cages were installed vertically (three at surface and three at depth) and three were installed horizontally as volitional cages. A plastic cone at the front of the vertical cages enabled the longitudinal axis of the cage to orient itself in the direction of the current flow, thereby providing in-cage water speeds less than those considered the maximum allowable (3 fish lengths/second) to avoid swimming fatigue (D. Alderdice, pers. comm.) Similarly, the upstream face of the volitional cages was covered with plastic material to provide shelter for fish. Surface cages were held with the longitudinal axis at the surface, with the bottom of the cage 10 cm (4 in.) below the water surface. Cages at depth rested on the pen framework such that the centerline of the longitudinal axis was at 1 m (3.2 ft) depth. The nine cages were positioned in a staggered fashion so that there was no possibility of a position effect. The pen was then placed in the water and attached by bow painter to a concrete block anchor. Finally, the floats were adjusted on the rails to place the pen at the proper position in the water column.

Chinook fry were captured July 12 by beach seining along the shore in front of Bert Irvines' Lodge where they were held in a net pen until being transferred to the study sites.

Prior to placing the fish in the cages, they were anesthetized in a 0.3 ml/l (0.033% by volume) solution of 2-phenoxyethanol, promptly weighed to ± 0.2 gram with an Ohaus electronic balance, measured (fork length) to ± 1 mm, and placed in a recovery bucket. Upon recovery, twenty chinook were gently introduced into each cage. Fish were placed in the nine cages (20 fish/cage) at the Cheslatta Falls holding pen (HP#1) midday, July 18. There were insufficient fish to fill all nine cages at the holding pen adjacent to Frank Schumans' property (HP#2), hence only six cages (two of each type) were filled midday, July 20. The other remaining cages with the exception of the third volitional cage were filled over a period to August 4.

The condition of the fish was checked daily. Mortalities were removed and promptly examined microscopically at x15 to x60 for external symptoms of GBT. Symptoms looked for included bubbles in the fins, skin tissue (integument), roof of the mouth and in large numbers of scale pockets on the lateral line; haemorrhaging in the eye area or at the base of the fins; difficulty in swimming and loss of equilibrium; flattening of the dorsal fin; and exophthalmia. Weight and fork length were recorded. Debris that collected on the cages was removed with gentle scrubbing. Fish were not fed and were dependant on drift that entered the cage as a source of food.

On July 24 the stage dropped rapidly grounding HP#2 in the shallows, leaving the middle surface cage suspended in the air and killing the fish in that cage. Modifications were made to prevent recurrence of this problem and nine fish, captured by electroshocking in Twin Creek, (Fig. 3) were placed in the cage July 31 and August 1. On August 4, additional fish were electroshocked at Twin Creek. Twenty were placed in the surface stern cage and 20 in the depth stern cage, neither of these cages having been previously filled.

The experiment at HP#1 concluded abruptly midday, August 7 when the pen broke free of its anchorage while being moved to quiet water and was destroyed downstream. Some of the fish were promptly recovered from cages but all were dead. The mortalities which had been recovered from surface and volitional cages were processed as usual and preserved; those recovered from depth cages were only preserved. The holding cages and a portion of the pen were removed from the river.

The experiment at HP#2 was concluded August 15 and 16. All remaining fish were processed and preserved. The holding pen was removed from the water and the cages cleaned and dismantled.

TOTAL GAS PRESSURE MEASUREMENTS

Continuous monitoring of TGP and related air and water quality parameters was conducted near the base of Cheslatta Falls from mid July to late September, and spot air and water quality measurements were taken at HP#1 and HP#2 during the GBT study (Fig. 3).

A Terrascience Ltd. Terra 8 data logger was installed at the site July 15. An Instrumentation Northwest Ltd. atmospheric barometric pressure (BP) probe, Terrascience Ltd. air and water temperature probes and a modified Novatech 300c were connected directly to the Terra 8. The data logger, BP and air temperature probes, and Novatech instrument and battery pack were installed in a Stevenson screen. The screen and the car battery which provided primary power to the Terra 8 were held in an open shed. The water temperature and tensionometer probes were submerged 0.5 to 1 m (1.6 to 3.3 feet) water depth in well mixed mainstem flow. The Terra 8 was programmed to record data from all probes hourly after initial calibration.

System maintenance included monitoring the Terra 8 to obtain real time probe values, confirming probe values (i.e. calibration), and changing batteries and silastic tubing in the tensionometer probe. Calibration involved checking BP, temperature, and tensionometer readings against spot measurements with a Pauline aneroid barometer, a thermometer accurate to ± 0.1 deg. C, and an additional Novatech 300B tensionometer, respectively. In addition, dissolved oxygen was measured using the Winkler titration method. The positions of the immersed probes were adjusted on several occasions as water stage changed.

The data in memory were downloaded via cassette tape recorder approximately once a week. The memory was then erased and the Terra 8 reset to begin another automatic data acquisition cycle. Two data gaps occurred. The first, July 18 to 21, was a result of incorrect programming. The second, September 8 to 10, was a result of the memory being full due to a delay in downloading and erasing.

The data on cassette tapes were transferred to floppy disk and imported to a spreadsheet format using Terrascience Ltd. software, an IBM PC and/or Compaq 286, and Lotus 123 Version 2.0.

Air and water quality spot measurements were made at HP#2 as well during the GBT experimental period. Water temperature was recorded on a thermograph installed as part of a temperature monitoring program. Intermittent barometric pressure, tensionometer, and D.O. measurements were made.

RESULTS

PHYSICAL-CHEMICAL RESULTS

Continuous automatic recording of water and air quality conditions at Cheslatta Falls using the Terra 8 data logger spanned the period July 12 to Sept. 23 in 1986. All TGP values were supersaturated. From the data logger records (N=1581), moist TGP ranged from 101.9% (2000 hrs Sept. 4) to 115.0% (0700 hrs Aug 23) and averaged 108.6%. There is a positive correlation between discharge at WCS station 08JA017 and moist TGP at Cheslatta Falls (Appendix 1, Fig. 5). A least squares regression line through these points gives a reasonable fit (i.e. r squared = 0.82).

The maximum, average, and minimum daily atmospheric and water quality values recorded at Cheslatta Falls by the data logger during the 1986 GBT experiment are presented in Appendix 2 with calculated moist TGP and discharge at HP#1. Appendix 3 presents spot air and water quality measurements at both sites. In general, the weather was mixed, with extended periods of clear, warm weather during the latter half of the experiment. Data from these appendices, biological results and weather observations are presented graphically in Figures 6 and 7.

TGP values derived from the data logger at Cheslatta Falls ranged from 107.2% to 115.0% averaging 111% (N=414) for the duration of the test at HP#1. Spot measurements (N=5) fell within this range and the O2/N2 ratio ranged from 0.93 to 0.98. TGP values at HP#2 (Frank Schumans') ranged from 106.5% to 111.3% and averaged 108.6% (N=20). The O2/N2 ratio ranged from 0.98 to 1.05 and averaged 1.01 (N=10).

BIOLOGICAL RESULTS

Data on fish length, weight, and mortality rates appear in Appendix 4. Total mortality by treatment (surface, volitional, and depth) at HP#1 and HP#2 appears with physical-chemical and weather data in Figures 6 and 7, respectively. Cumulative mortality by individual cage and treatments are given for HP#1 and HP#2 in Appendices 5 and 6 and Figures 8 and 9. At HP#1 there were three replicate cages of 20 fish each for each treatment for the

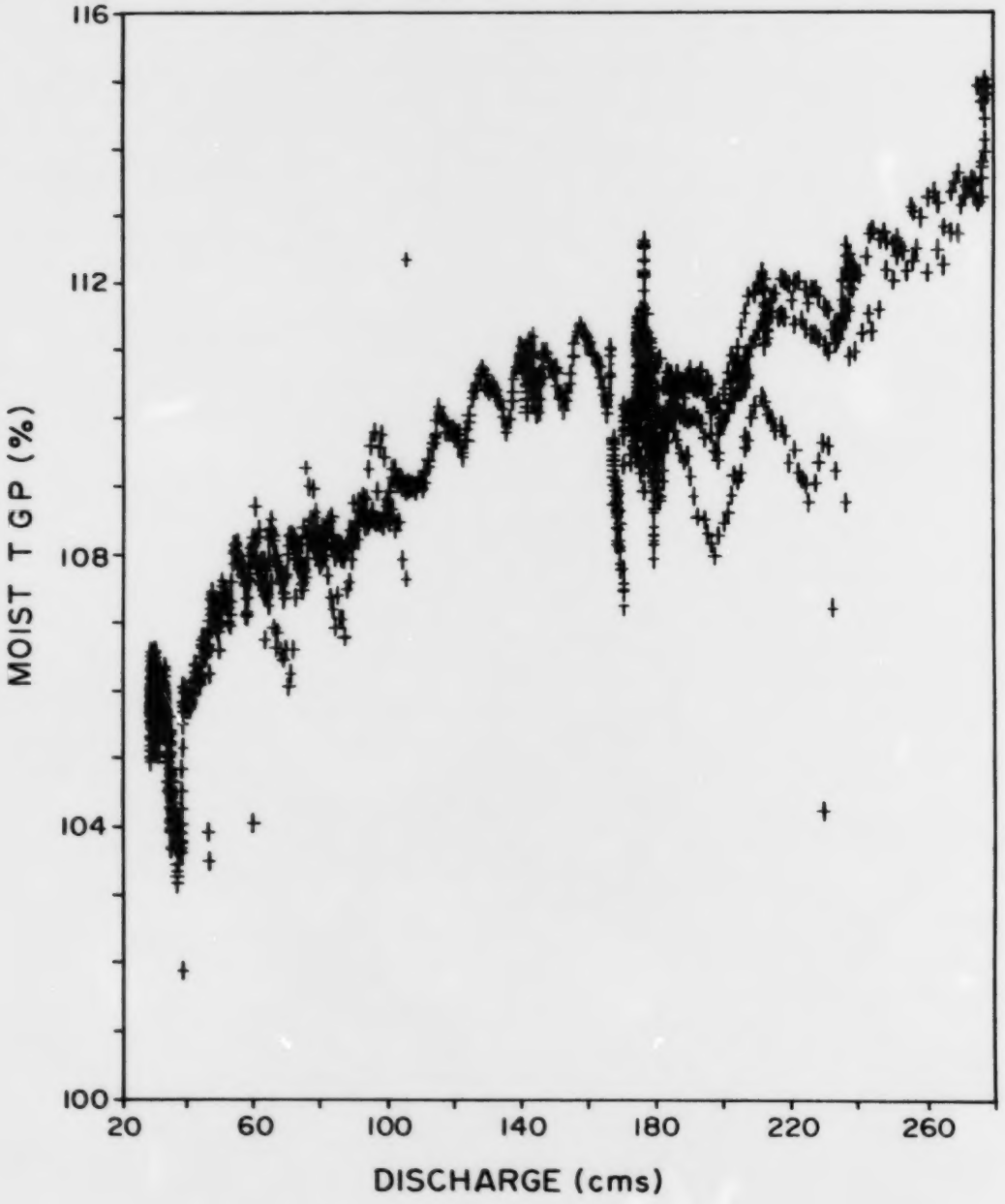

Fig. 5. Moist TGP versus discharge (CMS) at Cheslatta Falls.

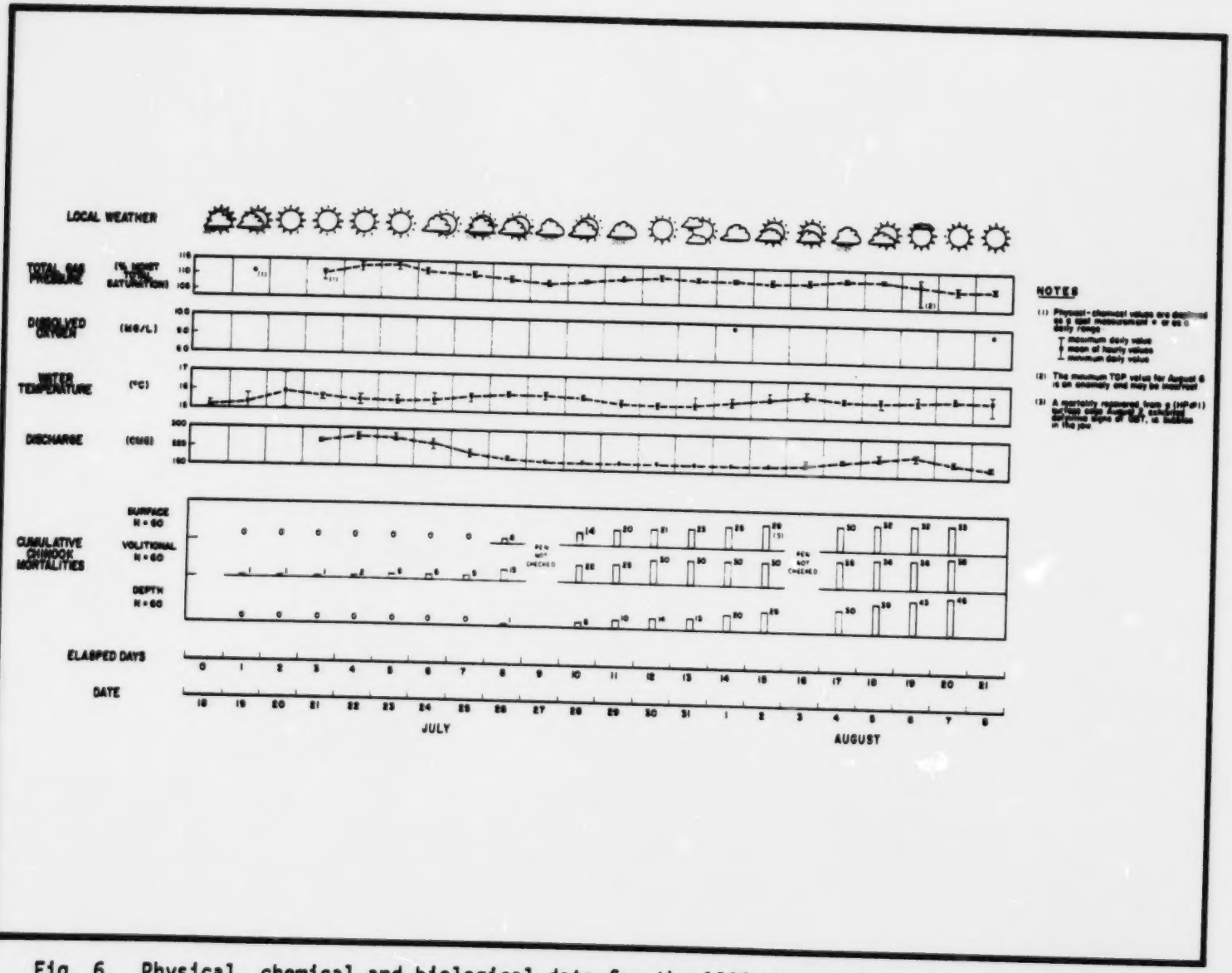

Fig. 6. Physical, chemical and biological data for the 1986 Nechako River in situ Gas Bubble Trauma (GBT) studies holding pen #1 at Cheslatta Falls.

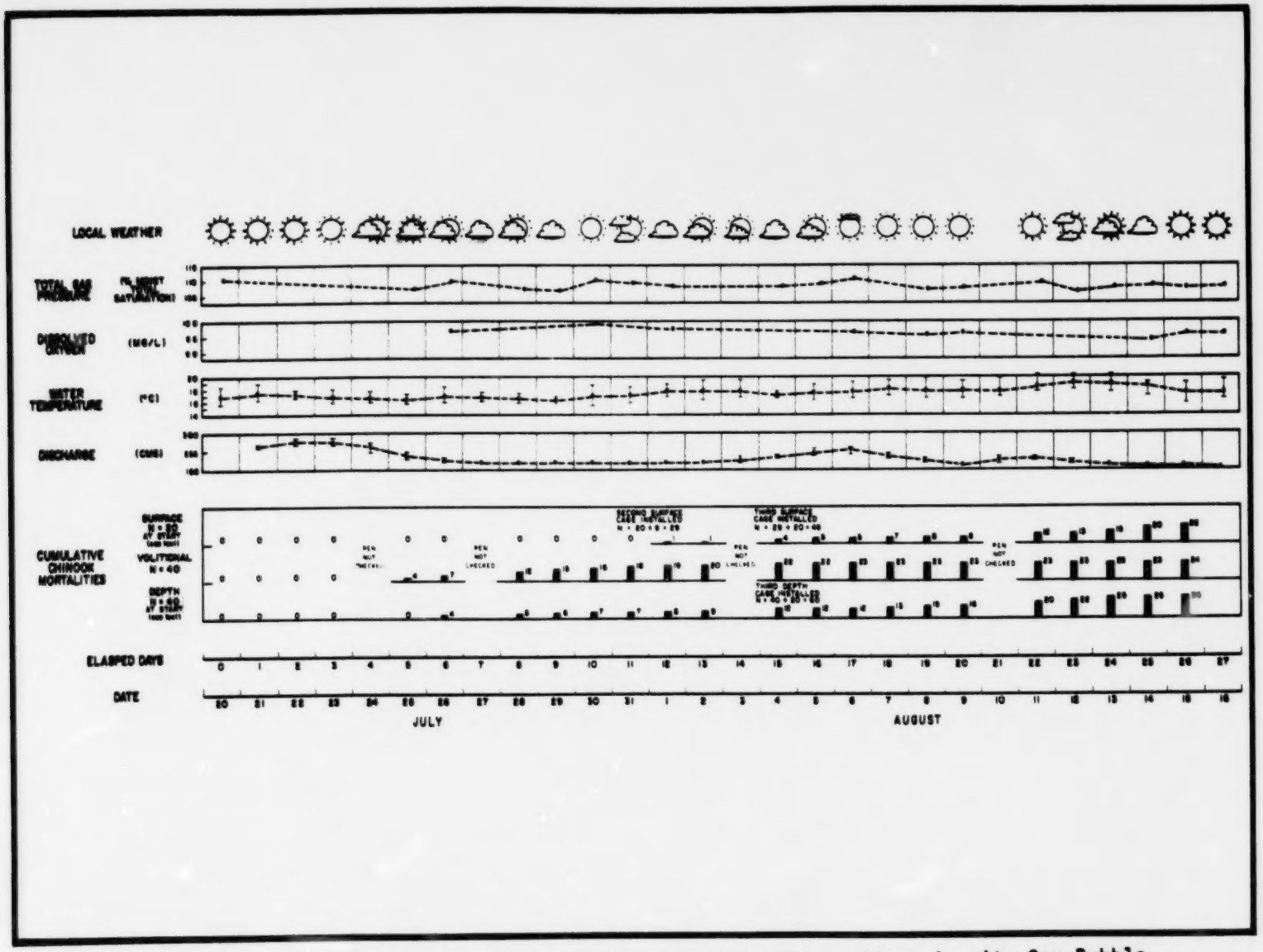

Fig. 7. Physical, chemical and biological data for the 1986 Nechako River in situ Gas Bubble Trauma (GBT) studies holding pen #2 at Frank Schuman's.

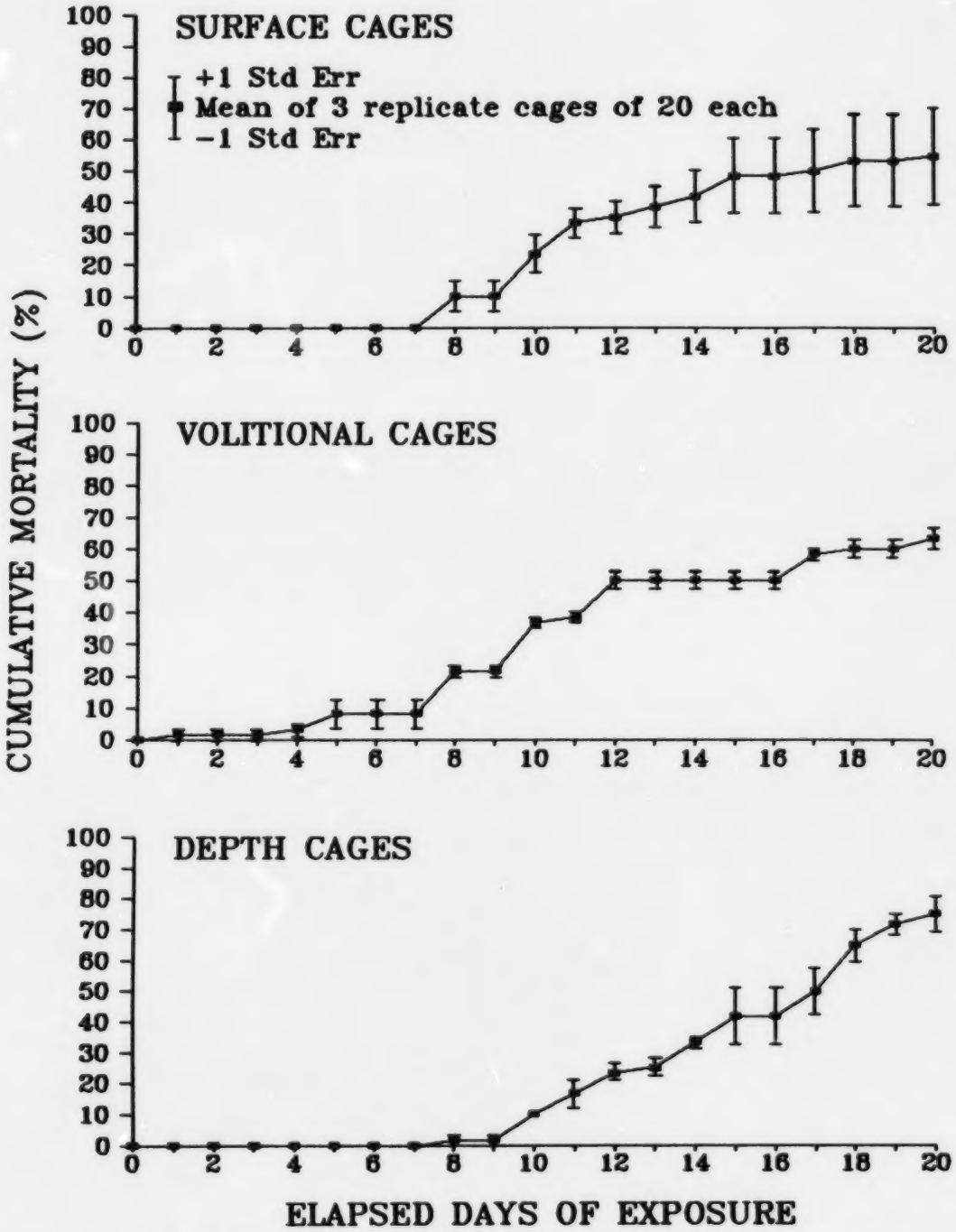

Fig. 8. Cumulative chinook mortality versus elapsed time at holding pen #1.

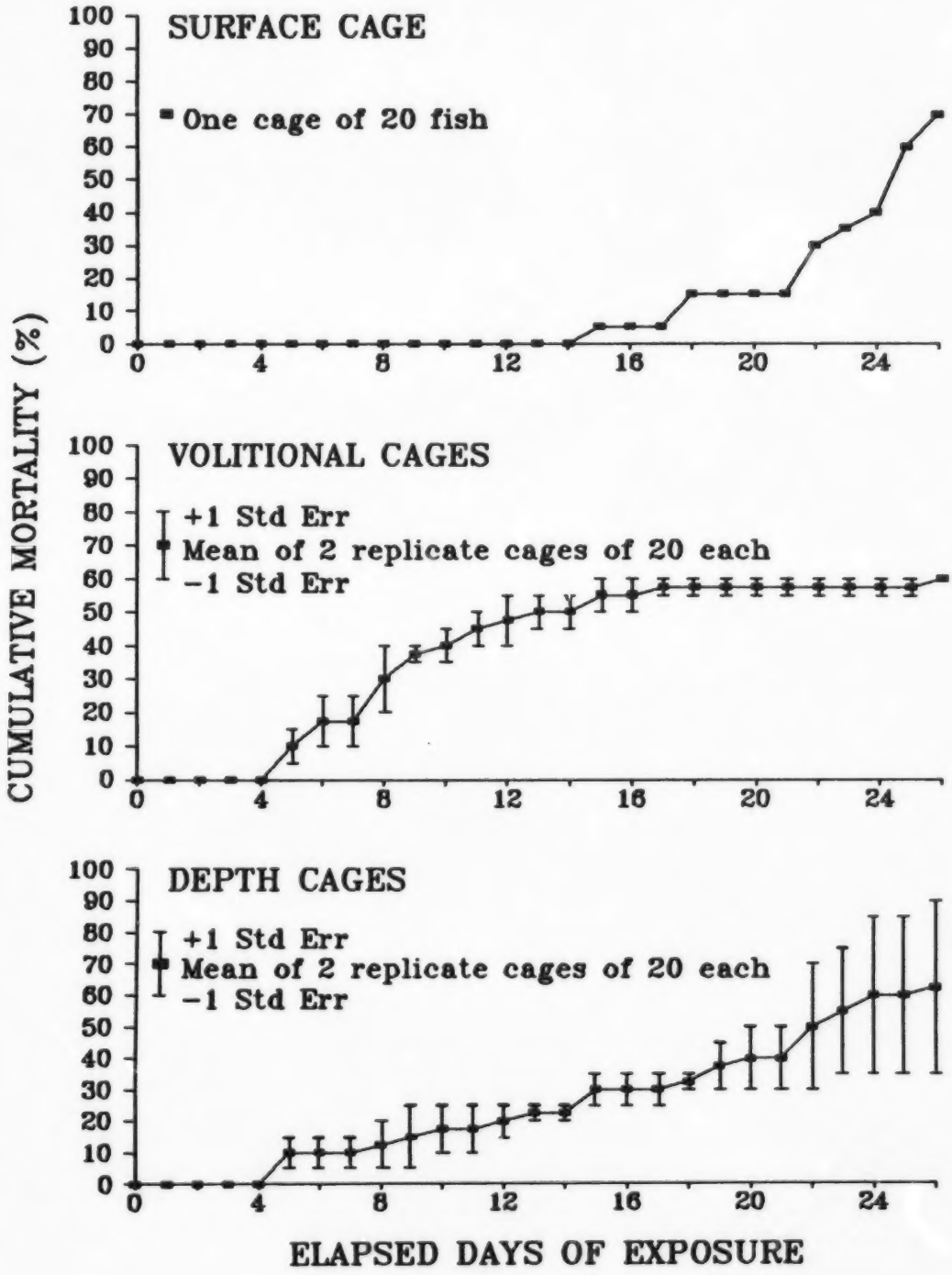

Fig. 9. Cumulative chinook mortality versus elapsed time at holding pen #2.

duration of the experiment. Total mortality at HP#1 ranged from 55% for the surface cages to 75% for the depth cages. At HP#2 there were two replicate cages of 20 fish each for volitional and depth treatments and one cage of 20 for surface treatment from beginning to end of the experiment (26 days). Total mortality at HP#2 ranged from 60% for the volitional cages to 70% for the surface cage. Approximately 10% (32 of 329 fish) of the mortalities exhibited exopthalmia regardless of whether they had been in surface, volitional or depth cages. However, only five fish exhibited haemorrhaging in the fins or eyes; one each from the HP#1 volitional and depth and HP#2 depth treatments and two from the HP#2 surface treatments. Gills were examined in some fish from all cages; in no case was there evidence of gas bubbles in the lamellae. The mortalities that were examined during the experiment often showed signs of necrosis which could have masked GBT symptoms. However, most fish examined at the end of the experiment did not exhibit GBT symptoms, and although thin appeared healthy. One fish showed signs of GBT (Plate 1), with bubbles visible in the dorsal region of the head in addition to exhibiting exopthalmia. This fish came from the surface stern cage at HP#1 after 15 days of exposure.

A summary of selected physical-chemical and fisheries results from the 1986 studies appears in Table 1.

DISCUSSION

The Nechako River and its tributaries support a large number of fish species of which chinook salmon, sockeye salmon and rainbow trout are of greatest economic interest. Chinook escapement to the river has averaged 1700 for the period 1978 to 1987 (Rowland 1988). Large numbers of chinook fry rear in the mainstem; a conservative population estimate of 43,000 fry was calculated for the 6 km section immediately downstream of Cheslatta Falls in early July, 1985 (Slaney 1985). Sockeye salmon utilize the Nechako River as a migration corridor during adult spawning migration and seaward juvenile migration of the Stuart, Nadina and Stellako River stocks (Fig. 1). These stocks averaged 19% of the total Fraser sockeye production in the 1979 to 1982 cycle (International Pacific Salmon Fisheries Commission, 1983).

The potential impact of elevated levels of TGP on these and other Nechako River fish species is a concern to fisheries agencies. In the 1986 study TGP values ranged from 107.2 to 115.0% averaging 111% (standard deviation 1.4%) during the test at HP#1 and from 106.5 to 111.3% averaging 108.6% (standard deviation 1.2%) at HP#2 (Figs. 6 and 7). These values are similar to TGP levels documented in previous years. DFO, the International Pacific Salmon Fisheries Commission (IPSFC) and Envirocon Ltd. (an environmental consulting firm contracted to Alcan) have measured gas saturation in the mainstem intermittently since 1974. Most measurements from the June-August period when solar heating is maximum and hence total gas pressure (and water temperature) is likely to be highest. These data indicate several trends in TGP as water flows over Cheslatta Falls and down the river

Plate 1. Macrophotograph of head of chinook fry (fork length 55 mm, weight 1.8 g) showing large bubbles on head and exopthalmia.

(Appendix 4, DFO unpublished manuscript, 1986). First, the saturation increases when water flows over Cheslatta Falls. Second, total gas pressure in water leaving the Cheslatta Falls plunge pool ranges from approximately 105 to 115% during July and August, the period of maximum solar heating. Third, there is a positive correlation between discharge over Cheslatta Falls during summer and resulting supersaturation in the water immediately downstream (Fig. 5., Appendix 1). Fourth, for a given range of flow, there is a general decrease in TGP downstream of the falls to Finmoore, approximately 40 km (25 miles) downstream of Vanderhoof. With respect to the fourth point, however, measurements at extremely low flow (less than 28 CMS [1000 cfs]) have not been made. Increasing TGP as water flows downstream may result under hot weather conditions. Finally, cyclic diurnal variations in TGP occur under some flow and atmospheric conditions.

Cumulative chinook mortality at HP#1 (Figs. 6 and 8) did not follow the trend that would be expected if all mortality was due to TGP. The first mortality in the volitional cage occurred immediately whereas surface and depth cage mortality commenced on the eight day. If all mortality was due to GBT, no mortality would occur in the depth cages. As mentioned in methodology, increased depth provides proportional protection against excess TGP because gas bubbles only form when the TGP is greater than the total pressure, which is the barometric pressure plus hydrostatic pressure. TGP decreases approximately 1% for every 10 cm depth, hence a fish exposed to surface waters of 111% saturation would be exposed to 101% saturation at one metre depth. Mortality should have occurred first in the surface cages and then to a lesser degree in the volitional cages. However, there was a period (commencing on day 10) when it appeared as though excess TGP was causing significant GBT-related mortality at HP#1. When mortality was analysed using oneway analysis of variance of arcsin transformed data, the cumulative mortality from day 10 to 13 was significantly ($p=.016$ to .023) different among the treatments. The mortality rate in the volitional cages was significantly different from the depth mortality; the surface mortality was not. This analysis is not conclusive, and after 13 days the trends in fish mortality due to GBT appear to have been completely masked by other causes (discussed below) of mortality.

Similarly, mortality at HP#2 did not follow the expected trend. No surface mortality occurred until the fifteenth day of exposure, whereas mortalities occurred in the volitional and depth cages on the fifth day. At the termination of the experiment mortality in the single surface cage was 70% versus 60% and 62.5% in the volitional and depth cages respectively. The absence of replicate surface cages prevents statistical verification of this result. Regardless, as was the case at HP#1, the mortalities at depth are indicative of other causes of death.

Jensen et al. (1986) predict (using Model 2) that, with an average 111% TGP at HP#1, 50% mortality of surface fish would be expected in 32 days, while fish at depth should not have shown mortality. Fifty percent mortality at 101% TGP is 189 days. This latter value is considered asymptotic, hence no response to TGP would be expected in depth cages. Of course, TGP fluctuated over time, as would be expected in a natural system. The impact of this fluctuation on fish response is not known.

Available evidence suggests that GBT can be divided into two forms, chronic and acute, depending on the level of TGP and period of fish exposure, life cycle stage of the fish, and the combination of O2/N2 ratio, temperature, and BP, variables which have a 'sparing' effect. Alderdice and Jensen (1985) concluded that a general boundary between chronic and acute toxicity may occur around 110 to 112% TGP. The values recorded at HP#1 averaged in this boundary (111%) and ranged from below (107.2%) to above (115.2%) the boundary. At HP#2, where average TGP was 108.6%, the ET50% are 75 and 492 days for surface and depth fish, respectively. Hence, no mortality due to TGP would be predicted at HP#2.

As mentioned, water temperature, atmospheric BP, and O2/N2 ratio variables affect mortality response to GBT. There is a paucity of information in the literature regarding the effects of these ancillary variables. Lower O2/N2 ratios are believed to exacerbate the GBT process. Meekin and Turner (1974) found that chinook juveniles experienced 50% mortality after 6 to 15 1/2 days exposure to TGP levels of 111.0 to 114.1% and 75.9% mortality in 86 days at 111.9%. Steelhead trout juveniles experienced 20% mortality after 11 days at 111.0%. However, the O2/N2 ratio was much lower in these studies, ranging from .58 to .64 versus ratios of 0.93 to 1.05 in the 1986 Nechako field studies.

In their review of dissolved gas supersaturation literature, Weitkamp and Katz (1980) make the point several times that the impact of TGP in the natural environment does not seem to be as severe as the artificial (hatchery or laboratory) environment. For example, Bouck (1976) found that natural fish populations exposed to 107 to 110% TGP in Oregon streams heated by geothermal action showed no signs of GBT whereas 105% TGP was sufficient to cause GBT in hatchery trout.

Factors other than excess TGP likely contributed to the observed mortality. Capture, handling, transportation and anaesthetic all cause stress to fish. In addition, even though efforts were made to provide shelter for the fish, they had reduced ability to find a suitable flow regime during confinement. Fish were not fed during the experiment, and although some small drift was observed flowing into the cages most drift was deflected. Finally, the fish used in the experiment were captured from the upper Nechako mainstem, where their exposure to elevated levels of TGP prior to capture would be a stressor. The combined effects of all of the above probably are responsible for the general high mortality rated observed in all test cages.

The significance of changes in length and weight of fish from the beginning to end of the experiment (Appendix 4) cannot be attributed to GBT for two reasons. First, the large fish mortality created two different populations at beginning and end of the experiment. Second, to test possible adverse effects of GBT on condition factor would require a simultaneous growth experiment with a large population.

One fish at HP#1 showed definitive signs of GBT (Plate 1); the fish exhibited gas bubbles in the head region and exopthalmia. This finding indicates that fish were exposed to a potential threshold level of TGP. Exopthalmia and haemorrhaging are symptoms of GBT as well as other diseases.

There was no clear association of either of these disease symptoms with TGP other than a higher incidence of exopthalmia at HP#1 (the surface fish exhibited the highest number) than at HP#2 (Table 1).

In summary, the 1986 field test produced one fish with definitive symptoms of GBT and significant mortality that may in part be due to GBT.

Further experiments must overcome or minimize the stress associated with holding fish in cages for several weeks. Feeding is essential, and would likely involve capturing juveniles in the spring and acclimating them to eat artificial fish food. Microscopic examination of sublethal effects is desirable and would require a large number of fish and on-site specialists. The remoteness of the test sites, the size of the river, and the variability of river, weather, and biological conditions further compound the difficulty of obtaining definitive results. This is especially true when attempting to document subtle, sublethal impacts of the elevated levels of TGP in the Nechako River. A significant committment of time and resources would be required to conduct more definitive studies.

ACKNOWLEDGEMENTS

A number of persons assisted the authors at various stages of this study and we thank them. Don Alderdice, Biological Sciences Branch, Nanaimo, and Gordon Ennis, Water Use Unit, Habitat Management, Vancouver, provided study development and direction. Equipment and logistical support was provided by Dave Munday, Coastline Environmental Services Ltd., Dennis Ableson, Pat Slaney, and Bob Land, Provincial Fisheries Branch, Herbert Irvine, Irvine's Lodge, Frank Schuman, Vanderhoof, Susan Blachut and Ron Byres, Nechako River Project. Constructive criticism of the report was provided by R. Bell-Irving, DFO Ottawa, and J. Mathers, G. L. Ennis, and M. Fretwell, Nechako River Project. Drafting services were provided by S. Galenzoski and Norm Gramchuk, XY3 Graphics. Special thanks to Frank King, Prince George, who assisted with the 1986 field work.

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Table 1. Summary of physical and biological results for 1986.

	HP#1 July 18 to Aug 8			HP#2 July 20 to Aug 16		
PHYSICAL-CHEMICAL						
	average	range		average	range	
Water Temp (deg. C.)	15.8	15.3-16.4		17.7	16.1-18.9	
Barometric Pres (mm Hg)	708.7	693.0-717.3		703.1	698.0-708.1	
Total gas pressure (%)	111.0	107.2-115.0		108.7	106.5-111.3	
Dissolved Oxygen (mg/l)	9.60	9.40-9.80		9.64	9.40-9.95	
O2/N2 ratio	0.95	0.93-0.98		1.01	0.98-1.05	
BIOLOGICAL						
	Surf	Vol	Depth	Surf	Vol	Depth
Mean FL (mm)*	60.2	61.6	61.3	62.1	61.8	59.4
Mean CF**	0.985	0.998	0.989	1.058	0.988	1.038
Number***	60	60	60	20	40	40
Mortality (number)	33	39	44	14	24	26
(%)	55.0	65.0	73.3	70.0	60.0	65.0
# Haemorrhaging	0	1	1	2	1	
Exopthalmia	11	6	7	2	4	2

* Fork length at beginning of experiment
** Condition factor at beginning of experiment
*** At beginning of experiment

Note: One fish held 15 days to mortality at HP#1 showed definitive symptoms of GBT (large bubble on head). See Plate 1.

APPENDICES

APPENDIX 1. Summary of 1986 TGP sampling program at Cheslatta Falls July 12 to Sept. 23 (n=1581).

Statistic	Parameter					
	Barometric Pressure (mm Hg)	Temperature Air (deg. C.)	Temperature Water (deg. C.)	Adjusted delta P (mm Hg)	Moist TGP (%)	Discharge (CMS)
Average	702.5	11.9	16.1	60.2	108.6	116.8
± 1 Std Dev	6.0	5.7	0.7	17.0	2.4	74.1
Range	674.2 to 717.3	-1.4 to 28.5	14.8 to 19.6	13.5 to 104.0	101.9 to 115.0	28.5 to 278.0

Regression statistical data for Fig. 5.

Moist TGP versus discharge (Q) at Cheslatta Falls

Constant	105.14
Std Err of Y Est	1.01
R squared	0.82
No. of observations	1581
Degrees of freedom	1579
x coefficient	0.029
Std Err of Coefficient	0.0003

APPENDIX 2. Summary of physical-chemical data from holding pen #1 (HP#1) at Cheslatta Falls during the 1986 GBT field study. Selected datalogger output, derived TGP and discharge for period July 18 to Aug. 16.

N.B. Discharge as measured at WSC Station 08JA017, no correction for travel time from Cheslatta Falls to Bert Irvine's.

DATE (mm/dd)		BAROMETRIC PRESSURE (mmHg)	AIR TEMPERATURE °C	WATER TEMPERATURE °C	ADJUSTED DELTA P (mm Hg)	MOIST TGP (%)	DISCHARGE M3/S	COMMENTS
	MAXIMUM						63.7	GBT
7/18	AVERAGE						62.6	EXPERIMENT AT
	MINIMUM						61.5	HP#1 BEGUN
	MAXIMUM						63.4	
7/19	AVERAGE			(NOT AVAILABLE)			63.2	
	MINIMUM						63.0	
	MAXIMUM						63.0	GBT
7/20	AVERAGE						62.4	EXPERIMENT AT
	MINIMUM						62.7	HP#2 BEGUN
	MAXIMUM	698.8	25.8	15.8	80.9	111.6	246.0	
7/21	AVERAGE	698.4	20.2	15.7	76.2	110.9	240.9	
	MINIMUM	697.9	16.7	15.5	61.3	108.8	236.0	
	MAXIMUM	698.8	19.6	15.8	100.4	114.4	277.0	
7/22	AVERAGE	697.7	15.4	15.6	91.7	113.1	264.7	
	MINIMUM	696.3	9.6	15.3	80.9	111.6	246.0	
	MAXIMUM	711.4	21.1	15.8	104.0	115.0	278.0	
7/23	AVERAGE	702.7	15.0	15.5	96.8	113.8	271.4	
	MINIMUM	693.0	9.2	15.4	86.5	112.2	254.0	
	MAXIMUM	711.0	18.1	15.9	90.7	112.8	254.0	
7/24	AVERAGE	710.2	13.7	15.6	84.7	111.9	238.3	
	MINIMUM	709.4	7.9	15.4	78.0	111.0	223.0	

APPENDIX 2 (CONT'D)

DATE (mm/dd)		BAROMETRIC PRESSURE (mmHg)	AIR TEMPERATURE °C	WATER TEMPERATURE °C	ADJUSTED DELTA P (mm Hg)	MOIST TGP (%)	DISCHARGE M3/S	COMMENTS
	MAXIMUM	712.8	17.1	15.9	83.4	111.7	223.0	
7/25	AVERAGE	711.1	12.0	15.8	77.6	110.9	207.2	
	MINIMUM	710.0	7.7	15.5	71.1	110.0	193.0	
	MAXIMUM	714.7	28.5	16.1	75.7	110.7	193.0	
7/26	AVERAGE	712.1	13.8	15.9	70.5	109.9	184.9	
	MINIMUM	710.5	8.5	15.8	63.0	108.8	180.0	
	MAXIMUM	717.3	18.3	16.1	67.4	109.4	180.0	
7/27	AVERAGE	715.6	13.3	15.9	63.5	108.9	179.2	
	MINIMUM	713.9	8.4	15.7	57.0	107.9	179.0	
	MAXIMUM	714.7	12.6	16.0	71.3	110.0	179.0	
7/28	AVERAGE	713.8	9.9	15.8	69.1	109.7	178.3	
	MINIMUM	712.8	8.0	15.7	65.8	109.2	178.0	
	MAXIMUM	712.8	14.7	15.8	81.7	111.6	178.0	
7/29	AVERAGE	710.1	9.9	15.6	76.5	110.8	177.8	
	MINIMUM	707.0	6.7	15.4	71.3	110.0	177.0	
	MAXIMUM	708.8	19.2	15.7	89.2	112.6	177.0	
7/30	AVERAGE	707.0	11.3	15.6	81.4	111.5	175.5	
	MINIMUM	705.2	2.9	15.4	74.1	110.5	175.0	
	MAXIMUM	708.9	20.4	16.0	81.3	111.5	175.0	
7/31	AVERAGE	707.8	14.0	15.6	76.7	110.8	174.6	
	MINIMUM	706.6	7.1	15.4	72.4	110.2	174.0	
	MAXIMUM	708.9	22.6	16.0	79.7	111.3	176.0	
8/01	AVERAGE	707.9	15.2	15.8	76.3	110.8	174.8	
	MINIMUM	707.0	9.7	15.6	72.1	110.2	174.0	

APPENDIX 2 (CONT'D)

DATE (mm/dd)		BAROMETRIC PRESSURE (mmHg)	AIR TEMPERATURE °C	WATER TEMPERATURE °C	ADJUSTED DELTA P (mm Hg)	MOIST TGP (%)	DISCHARGE M3/S	COMMENTS
	MAXIMUM	711.4	24.9	16.3	80.2	111.3	176.0	
8/02	AVERAGE	709.0	15.4	16.0	74.4	110.5	174.8	
	MINIMUM	707.0	8.1	15.9	67.4	109.5	173.0	
	MAXIMUM	710.0	21.3	16.4	81.7	111.6	206.0	
8/03	AVERAGE	708.8	15.5	16.2	75.1	110.6	187.4	
	MINIMUM	706.7	9.6	16.0	70.1	109.9	174.0	
	MAXIMUM	708.8	16.1	16.1	86.2	112.2	213.0	
8/04	AVERAGE	707.5	12.4	16.0	82.1	111.6	211.2	
	MINIMUM	706.2	9.5	15.9	78.5	111.1	206.0	
	MAXIMUM	711.1	21.8	16.2	85.6	112.1	237.0	
8/05	AVERAGE	709.4	13.2	16.0	82.9	111.7	224.0	
	MINIMUM	708.0	6.6	15.7	79.0	111.1	212.0	
	MAXIMUM	711.7	25.8	16.3	89.1	112.6	238.0	
8/06	AVERAGE	710.0	15.7	16.0	73.3	110.7	231.2	
	MINIMUM	708.4	7.2	15.8	30.1	107.2	219.0	
	MAXIMUM	712.4	24.4	16.3	73.3	110.3	219.0	END
8/07	AVERAGE	710.7	16.2	16.1	65.7	109.2	205.1	OF HP#1
	MINIMUM	709.5	9.0	16.0	57.0	108.0	191.0	EXPERIMENT
	MAXIMUM	710.2	24.6	16.4	71.0	110.1	191.0	
8/08	AVERAGE	705.5	14.6	16.1	67.8	109.6	181.2	
	MINIMUM	701.4	6.6	15.4	62.9	108.9	175.0	
	MAXIMUM	703.1	24.3	16.2	72.2	110.3	175.0	
8/09	AVERAGE	700.2	13.8	16.0	69.5	109.9	173.2	
	MINIMUM	697.1	4.2	15.8	65.4	109.4	172.0	

APPENDIX 2 (CONT'D)

DATE (mm/dd)		BAROMETRIC PRESSURE (mmHg)	AIR TEMPERATURE °C	WATER TEMPERATURE °C	ADJUSTED DELTA P (mm Hg)	MOIST TGP (%)	DISCHARGE M3/S	COMMENTS
8/10	MAXIMUM	698.2	25.5	16.6	74.6	110.7	203.0	
	AVERAGE	697.1	15.4	16.3	71.3	110.2	186.2	
	MINIMUM	694.8	6.7	16.0	66.9	109.6	173.0	
8/11	MAXIMUM	700.8	25.6	17.0	76.3	110.9	207.0	
	AVERAGE	698.8	17.8	16.4	72.6	110.4	202.7	
	MINIMUM	697.7	11.3	16.1	65.8	109.4	194.0	
8/12	MAXIMUM	702.6	22.8	16.8	71.8	110.2	194.0	
	AVERAGE	701.7	17.3	16.5	70.0	110.0	183.3	
	MINIMUM	700.8	13.8	16.1	68.1	109.7	174.0	
8/13	MAXIMUM	702.4	23.5	16.6	71.7	110.2	174.0	
	AVERAGE	700.5	16.5	16.4	63.2	109.0	170.7	
	MINIMUM	698.2	10.7	16.2	50.6	107.3	169.0	
8/14	MAXIMUM	700.1	19.1	16.8	63.7	109.1	169.0	
	AVERAGE	698.0	12.4	16.5	60.2	108.6	168.2	
	MINIMUM	695.7	5.2	15.8	56.5	108.1	167.0	
8/15	MAXIMUM	701.2	18.0	16.4	77.1	111.0	167.0	
	AVERAGE	698.6	9.7	16.1	69.5	109.9	166.1	
	MINIMUM	697.5	1.6	15.6	63.1	109.0	163.0	
8/16	MAXIMUM	701.9	20.6	16.3	79.6	111.4	163.0	END
	AVERAGE	698.7	10.2	16.0	75.5	110.8	156.5	OF HP#2
	MINIMUM	695.1	0.2	15.5	70.5	110.1	150.0	EXPERIMENT
SUMMARY OF VALUES DURING HP#1 OPERATIONAL PERIOD 7/18 TO 8/07 (EXCLUDING 7/18 TO 7/20) N=414								
7/18 TO 8/07	MAXIMUM	717.3	28.5	16.4	104.0	115.0	278.0	
	AVERAGE	708.7	13.8	15.8	77.6	111.0	194.9	
	MINIMUM	693.0	2.9	15.3	30.1	107.2	173.0	
SUMMARY OF ALL VALUES DURING FIELD STUDY (EXCLUDING 7/18 TO 7/20) N=630								
7/21 TO 8/16	MAXIMUM	717.3	28.5	17.0	104.0	115.0	278.0	
	AVERAGE	705.7	13.9	16.0	74.7	110.6	194.9	
	MINIMUM	693.0	0.2	15.3	30.1	107.2	150.0	

APPENDIX 3. Spot measurements of air and water quality parameters, TGP and ancillary values at HP#1 and HP#2 during the 1986 GBT field study.

SPOT MEASUREMENTS AT HP#1 (N=4 OR 6)

DATE (mm/dd)	TIME (hh:mm)	BAROMETRIC PRESSURE (mmHg)	RECORDED DELTA P (mmHg)	WATER TEMPERATURE °C	DISSOLVED OXYGEN (mg/l)	MOIST TGP (%)	% 02	% N2	02/N2
07/19	13:25	708.1	79	15.3		111.2			
08/01	16:20	708.1	80	15.7	9.83	111.3	106	113	0.94
08/07	16:20	701.7	66	18.6		109.4			
08/08	11:30	703.5	69	16.2	9.60	109.8	106	111	0.95
08/12	12:30	708.1	80	16.1	9.35	111.3	104	112	0.93
08/15	11:30	698.6	62	16.6	9.60	108.9	107	110	0.98
SUMMARY OF VALUES (N=4 OR 6)									
MAXIMUM		708.1	80.0	18.6	9.83	111.3	107.0	113.0	0.98
AVERAGE		704.7	72.7	16.4	9.60	110.3	105.8	111.5	0.95
MINIMUM		698.6	62.0	15.3	9.35	108.9	104.0	110.0	0.93

SPOT MEASUREMENTS AT HP#2 (N=9 OR 20)

DATE (mm/dd)	TIME (hh:mm)	BAROMETRIC PRESSURE (mmHg)	RECORDED DELTA P (mmHg)	WATER TEMPERATURE °C	DISSOLVED OXYGEN (mg/l)	MOIST TGP (%)	% 02	% N2	02/N2
07/20	14:00	707.3	72	17.7		110.2			
07/25	17:10	701.4	53	16.9		107.6			
07/26	16:30	700.4	71	18.3	9.70	110.1	112.2	110	1.02
07/28	16:40	699.4	52	17.2		107.4			
07/29	17:15	705.1	50	16.7		107.1			
07/30	14:40	707.1	72	17.0	9.95	110.2	110.9	110.3	1.01
07/31	15:45	705.4	66	17.8		109.4			
08/01	16:45	705.5	60	18.9	9.75	108.5	113.3	107.5	1.05
08/04	16:00	706	59	17.5		108.4			

APPENDIX 3 (CONT'D)

SPOT MEASUREMENTS AT HP#1 (N=4 OR 6)

DATE (mm/dd)	TIME (hh:mm)	BAROMETRIC PRESSURE (mmHg)	RECORDED DELTA P (mmHg)	WATER TEMPERATURE °C	DISSOLVED OXYGEN (mg/l)	MOIST TGP (%)	% O2	% N2	O2/N2
08/05	17:30	703.1	65	18.3		109.2			
08/05	16:15	702.6	76	18.3	9.65	110.8	111	111	1.00
08/08	14:20	705.4	52	18.3	9.55	107.4	110	109	1.02
08/09	13:52	701.8	57	17.2	9.63	108.1	109	108	1.00
08/11	15:10	699.9	68	18.9	9.55	109.7	112	110	1.02
08/12	15:10	703.2	46	18.6		106.5			
08/13	15:45	701	55	18.9		107.8			
08/14	15:60	698	59	18.0	9.40	108.5	108	109	0.98
08/15	13:40	700.7	53	17.0	9.60	107.6	110	107	1.03
08/16	13:15	700.8	56	16.2	9.60	108.0	108	109	0.98
SUMMARY OF VALUES (N=9 or 20)									
MAXIMUM		707.3	76.0	18.9	9.95	110.8	113.3	111.0	1.05
AVERAGE		702.8	60.1	17.8	9.64	108.6	110.2	109.1	1.01
MINIMUM		698.0	46.0	16.2	9.40	106.5	106.0	107.0	0.98

APPENDIX 4. Summary of fish length, weight, condition factor and mortality.

Holding pen: HP#1 at Cheslatta Falls
Species: Chinook
Date fish installed: July 18 Removed: August 7
Orientation: Surface

Cage Position	Bow	Middle	Stern	All
Beginning of Experiment				
N	20	20	20	60
Average FL (mm)	61.7	59.4	59.5	60.2
Range of FL (mm)	49-82	51-64	49-71	49-82
Average W (g)	2.4	2.1	2.2	2.2
Range W (g)	0.7-5.7	1.2-3.7	1.1-3.7	0.7-5.7
Average condition factor	0.967	0.957	1.031	0.985
Mortalities during experiment				
N	13	5	15	33
End of Experiment				
N				16
Average FL (mm)				62.3
Range of FL (mm)		(See note)		52-74
Average W (g)				2.8
Range W (g)				1.7-4.7
Average condition factor				1.154
Fish unaccounted for				11

Note When cages were recovered from the demolished holding pen the orientation (surface, depth, or volitional) could be determined but the position (bow, middle, or stern) could not.

APPENDIX 4 (CONT'D)

Holding pen: HP#1 at Cheslatta Falls
Species: Chinook
Date fish installed: July 18 Removed: August 7
Orientation: Volitional

Cage Position	Bow	Middle	Stern	All
Beginning of Experiment				
N	20	20	20	60
Average FL (mm)	62.1	61.7	61.1	61.6
Range of FL (mm)	55-74	54-73	54-77	54-77
Average W (g)	2.4	2.4	2.4	2.4
Range W (g)	1.5-4.0	1.4-4.0	1.6-4.7	1.4-4.7
Average condition factor	0.974	0.99	1.03	0.998
Mortalities during experiment				
N	12	12	15	39
End of Experiment				
N				14
Average FL (mm)				60.5
Range of FL (mm)		(See note)		52-72
Average W (g)				2.3
Range W (g)				1.3-3.4
Average condition factor				1.031
Fish unaccounted for				7

Note When cages were recovered from the demolished holding pen the orientation (surface, depth, or volitional) could be determined but the position (bow, middle, or stern) could not.

APPENDIX 4 (CONT'D)

Holding pen: HP#1 at Cheslatta Falls
Species: Chinook
Date fish installed: July 18 Removed: August 7
Orientation: Depth

Cage Position	Bow	Middle	Stern	All
Beginning of Experiment				
N	20	20	20	60
Average FL (mm)	61.7	60.5	61.7	61.3
Range of FL (mm)	52-76	51-74	43-72	43-76
Average W (g)	2.3	2.3	2.5	2.4
Range W (g)	1.3-4.4	1.2-4.0	0.8-4.0	0.8-4.4
Average condition factor	0.959	0.992	1.017	0.989
Mortalities during experiment				
N	14	17	13	44
End of Experiment				
N				
Average FL (mm)				
Range of FL (mm)		(See note)		
Average W (g)				
Range W (g)				
Average condition factor				
Fish unaccounted for				

Note When cages were recovered from the demolished holding pen the fish in the cages at depth where preserved but not measured, weighed, or examined.

APPENDIX 4 (CONT'D)

Holding pen: HP#2 at Frank Schuman's
Species: Chinook
Date fish installed: (See note) Removed: August 16
Orientation: Surface

Cage Position	Bow	Middle	Stern	All
Beginning of Experiment				
N	20	9	20	49
Average FL (mm)	62.2	73.6	56.8	62.1
Range of FL (mm)	51-76	57-91	46-69	46-91
Average W (g)	2.4	4.6	2.2	2.7
Range W (g)	1.1-4.2	1.8-8.8	1.0-3.6	1.0-8.8
Average condition factor	0.952	1.074	1.158	1.058
Mortalities during experiment				
N	14	7	1	22
End of Experiment				
N	6	2	18	26
Average FL (mm)	66.5	67.5	56.9	59.9
Range of FL (mm)	63-74	57-78	44-68	44-78
Average W (g)	2.6	3.9	1.8	2.1
Range W (g)	2.0-3.6	2.2-5.6	0.9-3.0	0.9-5.6
Average condition factor	0.886	1.184	0.944	0.949
Fish unaccounted for	0	0	1	1

Note Fish installed in bow cage July 20, middle cage July 31, and stern cage Aug 4.

APPENDIX 4 (CONT'D)

Holding pen: HP#2 at Frank Schuman's
Species: Chinook
Date fish installed: July 20 Removed: August 15
Orientation: Volitional

Cage Position	Bow	Middle	Stern	All
Beginning of Experiment				
N	20	20		40
Average FL (mm)	59.8	63.8		61.8
Range of FL (mm)	51-75	52-80		51-80
Average W (g)	2.2	2.7		2.5
Range W (g)	1.3-4.4	1.6-4.9		0.7-5.7
Average condition factor	0.984	0.991		0.988
Mortalities during experiment				
N	12	12		24
End of Experiment				
N	8	8		16
Average FL (mm)	58.3	67.1		62.7
Range of FL (mm)	50-71	55-79		50-79
Average W (g)	1.8	2.7		2.3
Range W (g)	0.9-3.1	1.5-4.1		0.9-4.1
Average condition factor	0.848	0.873		0.861
Fish unaccounted for	0	0		0

APPENDIX 5. Cumulative chinook fry mortality at holding pen #1 (HP#1) at Cheslatta Falls.

B= BOW CAGE S=STERN CAGE
M= MIDDLE CAGE T=TOTAL (BOW,MIDDLE, & STERN CAGES)

DATE (mm/dd)	ELAPSED DAYS	TREATMENT	COMMENTS	ABSOLUTE NUMBERS B	M	S	T	AVG MORT	STD ERR	PERCENTAGES B	M	S	AVG MORT (%)	STD ERR (%)
7/18	0	SURFACE VOLITIONAL DEPTH	EXPERIMENT BEGUN	(N=60) (N=60) (N=60)						(N=100%) (N=100%) (N=100%)				
7/19	1	SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		VOLITIONAL		0	1	0	1	0.3	0.3	0.0	5.0	0.0	1.7	1.7
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/20	2	SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		VOLITIONAL		0	1	0	1	0.3	0.3	0.0	5.0	0.0	1.7	1.7
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/21	3	SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		VOLITIONAL		0	1	0	1	0.3	0.3	0.0	5.0	0.0	1.7	1.7
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/22	4	SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		VOLITIONAL		0	1	1	2	0.7	0.3	0.0	5.0	5.0	3.3	1.7
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/23	5	SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		VOLITIONAL		0	3	2	5	1.7	0.9	0.0	15.0	10.0	8.3	4.4
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/24	6	SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		VOLITIONAL		0	3	2	5	1.7	0.9	0.0	15.0	10.0	8.3	4.4
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 5 (CONT'D)

DATE (mm/dd)	ELAPSED DAYS		COMMENTS	ABSOLUTE NUMBERS B	M	S	T	AVG MORT	STD ERR	PERCENTAGES B	M	S	AVG MORT (%)	STD ERR (%)
		SURFACE		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/25	7	VOLITIONAL		0	3	2	5	1.7	0.9	0.0	15.0	10.0	8.3	4.4
		DEPTH		0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		SURFACE		4	1	1	6	2.0	1.0	20.0	5.0	5.0	10.0	5.0
7/26	8	VOLITIONAL		4	4	5	13	4.3	0.3	20.0	20.0	25.0	21.7	1.7
		DEPTH		1	0	0	1	0.3	0.3	5.0	0.0	0.0	1.7	1.7
		SURFACE	PEN					2.0	1.0	20.0	5.0	5.0	10.0	5.0
7/27	9	VOLITIONAL	NOT					4.3	0.3	20.0	20.0	25.0	21.7	1.7
		DEPTH	CHECKED					0.3	0.3	5.0	0.0	0.0	1.7	1.7
		SURFACE		7	3	4	14	4.7	1.2	35.0	15.0	20.0	23.3	6.0
7/28	10	VOLITIONAL		8	7	7	22	7.3	0.3	40.0	35.0	35.0	36.7	1.7
		DEPTH		2	2	2	6	2.0	0.0	10.0	10.0	10.0	10.0	0.0
		SURFACE		8	5	7	20	6.7	0.9	40.0	25.0	35.0	33.3	4.4
7/29	11	VOLITIONAL		8	8	7	23	7.7	0.3	40.0	40.0	35.0	38.3	1.7
		DEPTH		2	3	5	10	3.3	0.9	10.0	15.0	25.0	16.7	4.4
		SURFACE		8	5	8	21	7.0	1.0	40.0	25.0	40.0	35.0	5.0
7/30	12	VOLITIONAL		9	10	11	30	10.0	0.6	45.0	50.0	55.0	50.0	2.9
		DEPTH		4	5	5	14	4.7	0.3	20.0	25.0	25.0	23.3	1.7
		SURFACE		9	5	9	23	7.7	1.3	45.0	25.0	45.0	38.3	6.7
7/31	13	VOLITIONAL		9	10	11	30	10.0	0.6	45.0	50.0	55.0	50.0	2.9
		DEPTH		4	5	6	15	5.0	0.6	20.0	25.0	30.0	25.0	2.9
		SURFACE		10	5	10	25	8.3	1.7	50.0	25.0	50.0	41.7	8.3
8/01	14	VOLITIONAL		9	10	11	30	10.0	0.6	45.0	50.0	55.0	50.0	2.9
		DEPTH		6	7	7	20	6.7	0.3	30.0	35.0	35.0	33.3	1.7

APPENDIX 5 (CONT'D)

DATE (mm/dd)	ELAPSED DAYS		COMMENTS	ABSOLUTE NUMBERS B	M	S	T	AVG MORT	STD ERR	PERCENTAGES B	M	S	AVG MORT (%)	STD ERR (%)
		SURFACE		11	5	13	29	9.7	2.4	55.0	25.0	65.0	48.3	12.0
8/02	15	VOLITIONAL		9	10	11	30	10.0	0.6	45.0	50.0	55.0	50.0	2.9
		DEPTH		6	12	7	25	8.3	1.9	30.0	60.0	35.0	41.7	9.3
		SURFACE	PEN					9.7	2.4	55.0	25.0	65.0	48.3	12.0
8/03	16	VOLITIONAL	NOT					10.0	0.6	45.0	50.0	55.0	50.0	2.9
		DEPTH	CHECKED					8.3	1.9	30.0	60.0	35.0	41.7	9.3
		SURFACE		11	5	14	30	10.0	2.6	55.0	25.0	70.0	50.0	13.2
8/04	17	VOLITIONAL		11	12	12	35	11.7	0.3	55.0	60.0	60.0	58.3	1.7
		DEPTH		8	13	9	30	10.0	1.5	40.0	65.0	45.0	50.0	7.6
		SURFACE		12	5	15	32	10.7	3.0	60.0	25.0	75.0	53.3	14.8
8/05	18	VOLITIONAL		11	12	13	36	12.0	0.6	55.0	60.0	65.0	60.0	2.9
		DEPTH		14	14	11	39	13.0	1.0	70.0	70.0	55.0	65.0	5.0
		SURFACE		12	5	15	32	10.7	3.0	60.0	25.0	75.0	53.3	14.8
8/06	19	VOLITIONAL		11	12	13	36	12.0	0.6	55.0	60.0	65.0	60.0	2.9
		DEPTH		15	15	13	43	14.3	0.7	75.0	75.0	65.0	71.7	3.3
		SURFACE	END	13	5	15	33	11.0	3.1	65.0	25.0	75.0	55.0	15.3
8/07	20	VOLITIONAL	OF HP#1	12	12	14	38	12.7	0.7	60.0	60.0	70.0	63.3	3.3
		DEPTH	EXPERIMENT	15	17	13	45	15.0	1.2	75.0	85.0	65.0	75.0	5.8

APPENDIX 6. Cummulative chinook fry mortality at holding pen # 2 (HP#2) adjacent to Frank Schumans' property.

B= BOW CAGE S=STERN CAGE
M= MIDDLE CAGE T=TOTAL (BOW,MIDDLE, & STERN CAGES)

N.B. At HP#1 there were three replicate cages for each treatment from beginning to end of the experiment. At HP#2 however, the were only two cages for volitional and depth treatments and one for surface from beginning to end of the experiment. (See methods). Standard error (STD ERR) cannot be calculated for the surface fish at HP#2 as there was only one cage.

DATE (mm/dd)	ELAPSED DAYS	TREATMENT	COMMENTS	ABSOLUTE NUMBERS						PERCENTAGES				
				B	M	S	T	AVG MORT	STD ERR	B	M	S	AVG MORT (%)	STD ERR (%)
7/20	0	SURFACE VOLITIONAL DEPTH	EXPERIMENT BEGUN		(N=20) (N=40) (N=40)						(N=100%) (N=100%) (N=100%)			
7/21	1	SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
		VOLITIONAL		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DEPTH		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/22	2	SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
		VOLITIONAL		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DEPTH		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/23	3	SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
		VOLITIONAL		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DEPTH		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/24	4	SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
		VOLITIONAL		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DEPTH		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/25	5	SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
		VOLITIONAL		1	3		4	2.0	1.0	5.0	15.0	0.0	10.0	5.0
		DEPTH		0	0		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 6 (CONT'D)

DATE (mm/dd)	ELAPSED DAYS	TREATMENT	COMMENTS	ABSOLUTE NUMBERS						PERCENTAGES				
				B	M	S	T	AVG MORT	STD ERR	B	M	S	AVG MORT (%)	STD ERR (%)
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
7/26	6	VOLITIONAL		2	5		7	3.5	1.5	10.0	25.0	0.0	17.5	7.5
		DEPTH		1	3		4	2.0	1.0	5.0	15.0	0.0	10.0	5.0
		SURFACE	PEN	0			0	0.0		0.0	0.0	0.0	0.0	
7/27	7	VOLITIONAL	NOT	2	5		7	3.5	1.5	10.0	25.0	0.0	17.5	7.5
		DEPTH	CHECKED	1	3		4	2.0	1.0	5.0	15.0	0.0	10.0	5.0
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
7/28	8	VOLITIONAL		4	8		12	6.0	2.0	20.0	40.0	0.0	30.0	10.0
		DEPTH		1	4		5	2.5	1.5	5.0	20.0	0.0	12.5	7.5
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
7/29	9	VOLITIONAL		7	8		15	7.5	0.5	35.0	40.0	0.0	37.5	2.5
		DEPTH		1	5		6	3.0	2.0	5.0	25.0	0.0	15.0	10.0
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
7/30	10	VOLITIONAL		7	9		16	8.0	1.0	35.0	45.0	0.0	40.0	5.0
		DEPTH		2	5		7	3.5	1.5	10.0	25.0	0.0	17.5	7.5
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
7/31	11	VOLITIONAL		8	10		18	9.0	1.0	40.0	50.0	0.0	45.0	5.0
		DEPTH		2	5		7	3.5	1.5	10.0	25.0	0.0	17.5	7.5
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
8/01	12	VOLITIONAL		3	11		19	9.5	1.5	40.0	55.0	0.0	47.5	7.5
		DEPTH		3	5		8	4.0	1.0	15.0	25.0	0.0	20.0	5.0
		SURFACE		0			0	0.0		0.0	0.0	0.0	0.0	
8/02	13	VOLITIONAL		9	11		20	10.0	1.0	45.0	55.0	0.0	50.0	5.0
		DEPTH		4	5		9	4.5	0.5	20.0	25.0	0.0	22.5	2.5

APPENDIX 6 (CONT'D)

DATE (mm/dd)	ELAPSED DAYS	TREATMENT	COMMENTS	ABSOLUTE NUMBERS B	M	S	T	AVG MORT	STD ERR	PERCENTAGES B	M	S	AVG MORT (%)	STD ERR (%)
		SURFACE	PEN	0			0	0.0		0.0	0.0	0.0	0.0	
8/03	14	VOLITIONAL	NOT	9	11		20	10.0	1.0	45.0	55.0	0.0	50.0	5.0
		DEPTH	CHECKED	4	5		9	4.5	0.5	20.0	25.0	0.0	22.5	2.5
		SURFACE		1			1	1.0		5.0	0.0	0.0	5.0	
8/04	15	VOLITIONAL		10	12		22	11.0	1.0	50.0	60.0	0.0	55.0	5.0
		DEPTH		5	7		12	6.0	1.0	25.0	35.0	0.0	30.0	5.0
		SURFACE		1			1	1.0		5.0	0.0	0.0	5.0	
8/05	16	VOLITIONAL		10	12		22	11.0	1.0	50.0	60.0	0.0	55.0	5.0
		DEPTH		5	7		12	6.0	1.0	25.0	35.0	0.0	30.0	5.0
		SURFACE		1			1	1.0		5.0	0.0	0.0	5.0	
8/06	17	VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		5	7		12	6.0	1.0	25.0	35.0	0.0	30.0	5.0
		SURFACE		3			3	3.0		15.0	0.0	0.0	15.0	
8/07	18	VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		6	7		13	6.5	0.5	30.0	35.0	0.0	32.5	2.5
		SURFACE		3			3	3.0		15.0	0.0	0.0	15.0	
8/08	19	VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		6	9		15	7.5	1.5	30.0	45.0	0.0	37.5	7.5
		SURFACE		3			3	3.0		15.0	0.0	0.0	15.0	
8/09	20	VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		6	10		16	8.0	2.0	30.0	50.0	0.0	40.0	10.0
		SURFACE	PEN	3			3	3.0		15.0	0.0	0.0	15.0	
8/10	21	VOLITIONAL	NOT	11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH	CHECKED	6	10		16	8.0	2.0	30.0	50.0	0.0	40.0	10.0

APPENDIX 6 (CONT'D)

DATE (mm/dd)	ELAPSED DAYS	TREATMENT	COMMENTS	ABSOLUTE NUMBERS						PERCENTAGES				
				B	M	S	T	AVG MORT	STD ERR	B	M	S	AVG MORT (%)	STD ERR (%)
8/11	22	SURFACE		6			6	6.0		30.0	0.0	0.0	30.0	
		VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		6	14		20	10.0	4.0	30.0	70.0	0.0	50.0	20.0
8/12	23	SURFACE		7			7	7.0		35.0	0.0	0.0	35.0	
		VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		7	15		22	11.0	4.0	35.0	75.0	0.0	55.0	20.0
8/13	24	SURFACE		8			8	8.0		40.0	0.0	0.0	40.0	
		VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		7	17		24	12.0	5.0	35.0	85.0	0.0	60.0	25.0
8/14	25	SURFACE		12			12	12.0		60.0	0.0	0.0	60.0	
		VOLITIONAL		11	12		23	11.5	0.5	55.0	60.0	0.0	57.5	2.5
		DEPTH		7	17		24	12.0	5.0	35.0	85.0	0.0	60.0	25.0
8/15	26	SURFACE	END	14			14	14.0		70.0	0.0	0.0	70.0	
		VOLITIONAL	OF HP#2	12	12		24	12.0	0.0	60.0	60.0	0.0	60.0	0.0
		DEPTH	EXPERIMENT	7	18		25	12.5	5.5	35.0	90.0	0.0	62.5	27.5